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Title: Engineering Analysis Baseline Model Requirements

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Engineering Analysis Baseline Model Requirements

Advanced Engineering and Analysis Group
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Introduction

The purpose of this document is to set requirements for the development, documentation, implementation, and maintenance of engineering analysis baseline models used by the Advanced Engineering and Analysis group to model and simulate systems. The intended audience of this document is the Engineering Technology and Design division Advanced Engineering and Analysis group—in particular the baseline model owners and users—and the Group Leaders and members of the Systems Engineering groups.

Section 1 presents a discussion of general concepts related to engineering analysis models and baseline models, including definitions of common terms used in this requirements document. It also presents the purpose and intentions of creating and using baseline models and exposes some underlying assumptions about what baseline models are supposed to be. Section 2 presents requirements on the general categories of: the Advanced Engineering and Analysis Group Leader and the baseline model owner; parts, materials, and load cases; the process of generating and using the model; and how the baseline model will be stored, maintained, and documented. This document presents requirements on the baseline model as well as some aspects of the development process and the people responsible for the development; it does not address how the results of simulations utilizing these models will be used to make assessments.

1 Discussion

What is a model? In the most general sense a model is anything used in any way to represent anything else. In the context of this document a model is an approximate numerical description of a system and its load cases specified in a form that can be interpreted by a computer program, which in turn can be used to carry out a simulation of the response of the system to those load cases. The description of the system is composed of descriptions of its components and their interactions, and these descriptions are also models. The relevant geometric information about a component is approximated by its mesh; the constitutive behavior of a material is approximated by a material model and its parameters; and interaction properties are approximated in terms of other models and parameters. The model of the system is the coherent combination of all of these models. It is a formal specification of underlying conceptualizations and assumptions, and it has a purpose: to simulate the response of the system to a set of load cases.

What is an engineering analysis baseline model? An engineering analysis baseline model is a collection of models for geometry, loading, interactions and materials for a system that serve as the foundation for structural and thermal response simulations that can be used by any engineering analyst to efficiently answer most of the past, current and future questions regarding the engineering state of the system.

What is expected of an engineering analysis baseline model? The model must be authoritative and general-purpose in order for analysts to extract valuable information from mechanical and thermal simulations. The model is authoritative when its demonstrated accuracy meets the needs of its users, and the model is general-purpose if it is flexible enough to be used for a large variety of load cases with minimal modifications. In order for any analyst to efficiently answer most questions using a baseline model its development and use must be well documented, and the model and documentation must be stored in an appropriate repository. A baseline model will be a group resource, used by multiple analysts over the lifespan of a system, and simulation results calculated from a baseline model should be reproducible over many years.

A baseline model will evolve over time and this evolution may incorporate improvements in modeling techniques and material models, additions to the range of load cases and operating environments that can be simulated, and improvements in computational resources and new capabilities of analysis codes. Because a typical use for a baseline model will be to investigate a new load case or the effects of a new or modified material behavior, modifications made by a user of a baseline model may be merged back into the baseline model at the discretion of the baseline model owner. Thus, a baseline model may also evolve over time based on improvements developed by its users. One of the responsibilities of the owner of a baseline model is to manage this continual evolution.

What is not part of an engineering analysis baseline model? First, this document does not define a standard set of applications used to define the part geometries and meshes or conduct an analysis. These aspects of defining and using a model are left to the discretion

of the model owner and users. Many of the baseline model goals stated in this document are intended to accommodate the use of alternative tools, such as the ability to replace one mesh generation tool with another. Second, a baseline model uses many material models, and the quality of its simulation results depends strongly on the capabilities of those material models. However, the development of a material model is considered a separate activity from the development of a baseline model, and therefore no requirements on the development of material models themselves are made here. The baseline model should use the best available material models for the environments being simulated, and the model choices should be explained and documented.

1.1 Definitions of Common Terms

Requirements

- shall: mandatory
- should: non-mandatory

Other

- baseline model: For the purpose of this document a baseline model is equivalent to an *engineering analysis baseline model*.
- candidate baseline model: An engineering analysis model that has yet to meet the minimum requirements presented in this document.
- engineering analysis baseline model: A collection of models for geometry, loading, interactions and materials for a system that serve as the foundation for structural and thermal response simulations that can be used by any engineering analyst to efficiently answer most of the past, current and future questions regarding the engineering state of the system.
- fork: A working copy that is not intended to be merged back into the baseline model.
- input files: Files that are directly read by an analysis code. Input files, or portions thereof, may be generated using other computer programs, such as mesh generation software, and scripted instructions.
- merge: The act of incorporating changes made to a working copy back into the baseline model, thus modifying the baseline model.
- model owner: Person who develops and maintains a baseline model and its documentation.
- model user: Person who uses a working copy of the baseline model to perform simulations.
- repository: A storage system that holds files and provides a record of past versions of its contents.
- working copy: The set of files checked-out from the baseline model repository. The baseline model may or may not be subsequently updated with the modifications made to a working copy—see *merge* and *fork*.

2 Requirements

All engineering analysis baseline model (EABM) requirements are enumerated as **EABM-** followed by a number.

2.1 General

EABM-1 The Advanced Engineering and Analysis Group Leader shall assign system model owners.

EABM-2 The model owner shall ensure that the requirements they are responsible for are met.

EABM-3 Efforts related to developing and implementing a baseline model shall be captured in a *Baseline Model Manual* following the requirements in this document.

> **Comment:** The recommended tool for generating and maintaining a *Baseline Model Manual* is the Advanced Engineering and Analysis collaboration and knowledge-base website. The website facilitates the implementation of living and evolving documentation that can be efficiently produced, edited, and searched by all analysts.

EABM-4 The *Baseline Model Manual* shall specify the model revision numbers with which it is associated.

> **Comment:** Large analysis models are composed of many geometric, material, interface, and loading models, all with their own unique revision numbers. A baseline model, as a collection of all these models, will also have its own unique revision number. The documentation will capture the baseline model revision number and the unique revision numbers for the geometric, material, etc. models with which it is generated.

2.2 Parts, Geometry & Meshing

Systems are composed of many parts and sub-assemblies based on engineering drawings. Models of those components will be generated based on pedigreed drawings or solid models, and at least use nominal dimensions.

EABM-5 All drawings and solid models used for the baseline model shall have a traceable origin and correctly represent the parts and assemblies in the respective system.

> **Comment:** The recommended tool for locating part and assembly drawings is the Weapons Product Data Management system.

EABM-6 Models of parts and assemblies shall be created using basic dimensions—i.e. not reference dimensions—unless the part is better represented by as-built geometry.

EABM-7 The procedures used to generate any derived dimensions shall be documented in the *Baseline Model Manual*; derived dimensions shall also be explicitly identified as such.

Comment: Derived dimensions are values that are generated from basic dimensions in order to properly generate a geometric model.

Rationale: There may be multiple options for generating derived dimensions, and those options may produce different results. Documentation is necessary to remove the ambiguity in how the dimensions were computed.

EABM-8 Models of parts and assemblies should use parameterized dimensions.

Rationale: Using parameterized dimensions aids in studies of statistical variations in part and assembly geometries.

EABM-9 The dimensions used to generate a geometric model shall be traceable and verifiable between the values in a drawing and the values used to generate the geometry.

Comment: The suggested method for satisfying this requirement is to label the basic dimensions in a part's or assembly's respective electronic-format drawing, e.g. PDF or solid model, and then reference those annotated dimensions in the scripts used to generate the geometry.

This requirement does not apply to commercial off-the-shelf parts for which drawings might be unavailable, or when electronic-format drawings are not available.

EABM-10 Annotated drawings of parts and assemblies used to generate the baseline model shall be documented in the *Baseline Model Manual*.

EABM-11 Models of parts and assemblies should be created with the ability to efficiently include or omit features.

EABM-12 The assembled state of all parts in a system model shall be consistent with the system's assembly drawings.

Comment: While there are different means of modeling assembly, the process must produce an end-result consistent with the system.

EABM-13 The assumptions and idealizations made in the geometric modeling of a system's parts and assemblies shall be documented in the *Baseline Model Manual*.

Comment: The documentation will include a discussion of what parts were included and omitted in the model, what part features were captured or omitted, how part interactions such as contact definitions where chosen, and how the assembly process and procedures were accounted for.

EABM-14 A description of each part and assembly used in the baseline model shall be documented in the *Baseline Model Manual*, and the description shall include the part or assembly name as specified in its corresponding drawing or solid model, the part or assembly name used in the model, the part number, the drawing name and number, the annotated drawing with labeled dimensions, the material specification for the part, the material name as specified on the drawing and the material name as used in the model.

Rationale: It is common to refer to a part in various ways: sometimes by name, sometimes by material, sometimes by part number. Furthermore, some parts are referred to by function, such as "mount," some materials have multiple names, and some material names are insufficient to distinguish various processing methods that produce different material properties.

2.3 Material Assignments & Models

Proper assignment of material models will ensure that parts are modeled using the correct materials per their material specifications. The material models will be selected to sufficiently reproduce appropriate physical behaviors and the model parameters will be correct for the materials for the desired environments. For example, if a part's material specification lists stainless steel 304L as the material and that part is loaded in a way that produces elastic and plastic strains, then an elastic-plastic material model will be chosen and that model will be supplied the appropriate parameters for the stainless steel. Furthermore the model parameters will have acceptable sources and pedigree in terms of supporting test data and documentation.

EABM-15 The material assigned to each part shall match what is listed in the part's material specification document.

EABM-16 Material models shall be selected to capture the expected physical behaviors during actual loading conditions.

Example: If the part will be subjected to loads producing small elastic and plastic strains, then an elastic-plastic material model may be appropriate.

EABM-17 Material model parameters shall correctly represent the material being modeled in the appropriate loading regime.

Example: The parameters required to define any elastic-plastic material model include density, elastic modulus, initial yield strength, and hardening behavior. The parameters used for an elastic-plastic model of the aluminum 6061-T6 material must be correct for that material and use consistent units.

EABM-18 All material model parameters shall have traceable sources.

Comment: The recommended tool for locating material model parameters is the LANL Weapon Systems Engineering Material Database. This database is intended to be the repository of material model information and material model parameters for all baseline models. If a new or modified material model parameter set is required by a baseline model, then the baseline model owner will request that the new parameter set be added to the database and may use the parameter set before it has been added. Input files and previous models are examples of unacceptable sources for material model parameters.

EABM-19 The source of material model parameters should contain a reference to test data, a discussion of the data, and documentation of the material model calibration and validation processes.

EABM-20 Choices of material models and material model parameters, including assumptions, idealizations, and modifications shall be documented in the *Baseline Model Manual*.

2.4 Load Cases & Responses

A baseline model will be used to simulate the structural and/or thermal response of a system subject to a variety of environments. A load case refers to a particular set of loads—for example: applied forces, ambient temperature changes, or energy deposition rates—associated with one environment. Typically, a simulation will consist of a series of load cases, beginning with system assembly, continuing through all important environments to which the system is exposed—for example: transportation, storage, etc.—and completing with an event of particular interest—for example: delivery, or an abnormal environment. A response of interest is some particular structural or thermal quantity calculated in the simulation that is of importance in an assessment of the system's response.

EABM-21 The baseline model shall be capable of simulating the initial state of the system, which includes: (1) the internal mechanical loads produced by gravity and assembly; and (2) the stresses produced by thermal strains due to expected temperature distributions.

> **Rationale:** It is expected that any model that is capable of simulating the assembly and thermal equilibrium load cases could be extended by a user to simulate additional load cases, and that these extensions could be subsequently merged back into the baseline model.

EABM-22 Load cases and responses of interest shall be identified by collaboration between the model owner and system engineers. A memorandum documenting the additional load cases and responses of interest should be acquired from the system engineers.

EABM-23 Other load cases shall be added to the baseline model at the discretion of the model owner.

EABM-24 Output requests relevant to each of the identified system responses of interest for each load case shall be specified in the input file.

EABM-25 The *Baseline Model Manual* shall briefly describe all load cases referenced in **EABM-21**–**EABM-23** and shall reference technical reports authored by the model owner or model users that fully describe each of those load cases and their simulated responses.

2.5 Model Generation, Use & Results

Ideally all analysis input files will be generated using an automated set of instructions so that the number of interactive model-building steps can be minimized and the process will

be repeatable. The desire is that all users will be able to generate an identical model from the same set of baseline model files.

EABM-26 Model and input file generation shall be achieved with an automated process that includes scripted sets of instructions.

EABM-27 Documentation of the model and input file generation process shall be described in the *Baseline Model Manual* and include a description of all required software tools, software version numbers, scripts, commands, and instructions used to create the models and input files.

EABM-28 The model and input file generation process shall include automatic verification of part masses, and the verification shall be documented in the *Baseline Model Manual*.

EABM-29 Instructions describing how an analysis job is submitted shall be described in the *Baseline Model Manual*.

EABM-30 Any scripts that are used to post-process analysis results shall be described in the *Baseline Model Manual*, and the scripts should be included in a repository—see Section 2.7.

2.6 Modifiability

Ease of modification is a key requirement of a baseline model, even though it is impossible to quantify how easy it is to modify a model. Continual modifications should be expected and desirable, and a good model generation process will make this easier to accomplish.

EABM-31 A working copy of the baseline model should be easily modifiable by model users.

> **Comment:** The *Baseline Model Manual* will assist model users in obtaining and modifying a working copy in order to conduct new simulations.

EABM-32 Modifications that should be possible to implement within an average time of one week include the following: (1) substitution of material models and material properties; (2) modification of mesh density for individual parts or for the whole model; (3) modification of part geometry, including dimensions within tolerances and assembly configuration (tolerance stack-up); and (4) modification of interactions, loads, and boundary conditions.

> **Comment:** At the discretion of the model owner, modifications to a working copy of the baseline model made by a model user should be considered for merging back into the baseline model.

EABM-33 A test-based change control procedure shall be implemented for testing and merging of approved modifications.

> **Rationale:** An automated procedure for testing changes and managing merges will relieve baseline model owners from having to do so.

2.7 Storage

How and where a baseline model is stored is important for many reasons. The storage system controls who can access the model and who can modify it. It also controls how older versions of the model files are retained and made available. These access controls and retention policies are important from a quality assurance standpoint.

EABM-34 All files used to develop a candidate baseline model, produce a simulation, and post-process its results shall be stored and maintained in a model repository.

> **Comment:** The storage solutions used for the baseline models will be the Advanced Engineering and Analysis repository and the collaboration and knowledge-base website, depending on the types of files that will be stored.
>
> **Comment: Files that should be stored.** Files such as meshing scripts that are needed to regenerate portions or the entirety of the analysis code input file need to be stored.
>
> **Comment: Files that should not be stored.** Any files that are created in the model regeneration process do not need to be stored. An example of such files is one containing mesh data. Software (executables), solid models, and drawings that are stored in PDMLink need not be stored in the repository. Files created by the analysis code itself, such as simulation results files, need not be stored in the repository. In General, binary files should not be stored in the repository.

EABM-35 Any prior versions of the files used to produce a simulation and post-process the results of a baseline model shall be retrievable from the repository.

> **Comment:** This requirement assumes that prior analyses can be reproduced using currently available hardware and software.

2.8 Dependencies

EABM-36 The analysis code and all other software applications that have been used to generate the baseline model or conduct simulations shall be identified in the *Baseline Model Manual* by name and version, and the computers used to run these programs shall be identified in the *Baseline Model Manual* by name.

EABM-37 The Advanced Engineering and Analysis group leader shall certify that all software identified in **EABM-36** meets the requirements of the Advanced Engineering and Analysis group and Engineering Technology and Design division Software Quality Assurance policies.

2.9 Verification & Validation

Verification and validation of simulations are recognized to be important parts of developing and using models. However, it is difficult to state requirements applicable to baseline models because experiments are typically done on test assemblies that are surrogate representations

of the system design. Experimental data from tests on lower fidelity assemblies can be used for some form of validation, but only to draw conclusions regarding the parts of the analysis model that come from the baseline model. An excellent description of verification and validation of simulations is found in [2].

Calculation verification is used to quantify the error of a numerical simulation by demonstration of convergence and, if possible, to provide an estimation of the numerical errors induced by the use of the model. The types of errors being identified and removed by calculation verification include insufficient spatial or temporal discretization, insufficient convergence tolerance, incorrect input options, and finite precision arithmetic. Insufficient grid refinement is typically the largest contributor to error in calculation verification assessment.

Validation assessment is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. The goal of validation is to quantify confidence in the predictive capability of the model by comparison with experimental data.

EABM-38 Calculation verification shall be performed for every response of interest for every load case identified in **EABM-21**–**EABM-23**, and results of this verification shall be documented in the *Baseline Model Manual*.

EABM-39 Verification of the model generation process shall be performed to ensure that the results are self- and physically-consistent based on a set of consistency checks that are derived by the group of model owners.

> **Example**: Results are self-consistent if parts do not grossly overlap, and they are physically-consistent if part and assembly masses are sufficiently correct.

EABM-40 Results from analyses performed using a combination of models of high and lower fidelity parts should be validated for the load cases and measurements used in the experiment.

EABM-41 All validation data shall have traceable sources.

EABM-42 The sources of validation data shall contain documentation of the test procedure, a discussion of the data, and documentation of the data processing [1].

2.10 Maintenance

Periodic maintenance of a baseline model is necessary to ensure that the numerous changes that occur in the engineering definition of the system and the computing environment used to conduct simulations are tracked and reflected in the model. This maintenance could occur annually as part of the LANL annual assessment program.

EABM-43 The baseline model owner shall solicit, track, and resolve problems and feature-requests using a searchable archive that is accessible by any user.

> **Comment:** The recommended tool for soliciting, tracking, and resolving problems and requests is the Advanced Engineering and Analysis software development management tool.

EABM-44 Maintenance and re-assessment of the model shall include the following: (1) a check for relevant updates to part drawings, for updated material assignments, material models, or material model parameters, (2) verification that the model generation process continues to operate as expected and produces sufficiently similar input files, (3) verification that major-release updates of the analysis code produce acceptable changes to model results, and (4) a determination of whether user improvements can be considered as updates to the baseline model.

> **Comment:** The recommended tool for completing re-assessments is the Advanced Engineering and Analysis continuous integration server.

EABM-45 If the re-assessment produces changes to the configuration or load cases of a baseline model, then all affected simulations shall be re-run and significant differences in simulation results shall be documented in the *Baseline Model Manual*.

EABM-46 Results of all maintenance and checks shall be documented in the *Baseline Model Manual*.

EABM-47 Whenever the baseline model is updated, the main text in the *Baseline Model Manual* shall document the current state of the baseline model, which should be identified by repository version number, while an appendix should be created to keep a log of changes from one version to the next.

2.11 Acceptance & Reacceptance

EABM-48 A candidate model shall be considered a baseline model following a peer review by a committee selected by the Advanced Engineering and Analysis Group Leader and subject to the minimum requirements. **EABM-1**, **EABM-3**–**EABM-7**, **EABM-9**, **EABM-10**, **EABM-12**–**EABM-18**, **EABM-20**–**EABM-22**, **EABM-24**–**EABM-30**, **EABM-34**, **EABM-36**, **EABM-38**, **EABM-39**, **EABM-41**, **EABM-42**.

EABM-49 Formal acceptance of a candidate baseline model shall come from the Advanced Engineering and Analysis Group Leader.

EABM-50 Compliance of a baseline model with the relevant **EABM** requirements shall be tracked and updated as needed.

> **Comment:** Tracking of compliance will be documented in the *Baseline Model Manual*.

EABM-51 If the peer review process deems a candidate baseline model to be substantially out of compliance, then the baseline model owner shall develop and implement a plan for improving compliance.

> **Comment:** The plan will be documented in the *Baseline Model Manual* and related efforts will be captured and tracked using the Advanced Engineering and Analysis software development management tool.

EABM-52 Whenever the baseline model is updated due to maintenance, as described in Section 2.10, then its acceptance shall be renewed per **EABM-48** and **EABM-49**.

References

[1] C. Haynes, "Test Data Workflow," W-SE-0034, rev. B, May 2017.

[2] B. H. Thacker, S. W. Doebling, F. M. Hemez, M. C. Anderson, J. E. Pepin, and E. A. Rodriguez, "Concepts of model verification and validation," LA-14167-MS, LANL, October 2004.